

Aug. 26, 1969

M. BLOOM
METHOD OF CATHODICALLY SPUTTERING A LAYER OF
SILICON HAVING A REDUCED RESISTIVITY
Filed July 7, 1966

3,463,715

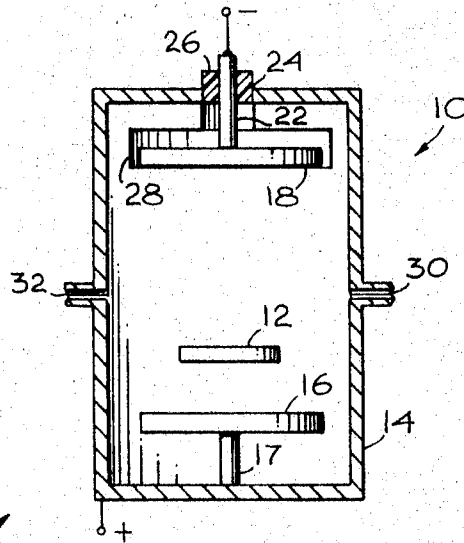


Fig. 1

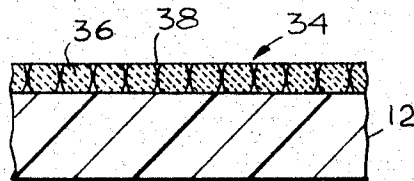


Fig. 2

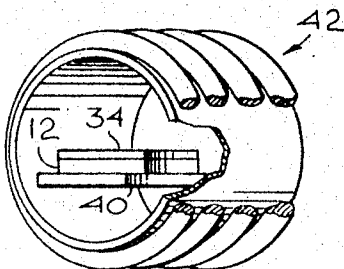


Fig. 3

INVENTOR.
MURRAY BLOOM
BY Arthur Feilich
ATTORNEY

1

3,463,715

METHOD OF CATHODICALLY SPUTTERING A LAYER OF SILICON HAVING A REDUCED RESISTIVITY

Murray Bloom, Los Angeles, Calif., assignor to TRW Inc., Redondo Beach, Calif., a corporation of Ohio
Filed July 7, 1966, Ser. No. 563,482
Int. Cl. C23c 15/00

U.S. Cl. 204—192

5 Claims

ABSTRACT OF THE DISCLOSURE

There is disclosed a method of sputter depositing semiconductor materials such as silicon on a substrate to produce a silicon layer having high conductivity in both the longitudinal direction parallel to the surface of the substrate and in a direction normal or perpendicular to the substrate surface. The method comprises the steps of sputter depositing the silicon in a reduced pressure atmosphere to form a silicon layer on the substrate and thereafter heating the deposited layer in an environment of pure hydrogen preferably at a temperature of about 1,000° C. for approximately 15 minutes.

This invention relates generally to methods of fabricating semiconductor devices and more particularly to improvements in methods employing sputtering for depositing semiconductor material such as silicon.

Various sputtering devices suitable for depositing semiconductor material, such as silicon, are known in the art. Essentially all of these devices are comprised of a cathode, formed of the material to be deposited, and an anode supported within an enclosed sputtering chamber. A substrate upon which the sputtered material is to be deposited is also supported within the chamber. The chamber is initially evacuated and a gas, such as argon, is then let in. The gas is then ionized by a sufficiently high potential applied between the cathode and anode. At an appropriate gas pressure, the potential will maintain a discharge within the chamber. The discharge is due to a multiplication process in which the collision between positive ions and gas atoms produces more positive ions and electrons. The positive ions are, of course, attracted to the cathode and the electrons to the anode. En route, they each collide with gas atoms thus producing more positive ions and electrons. When the positive ions finally reach the cathode, they strike with such energy that atoms of the cathode material are ejected and collect on the substrate. By properly controlling various parameters such as temperature, pressure, duration, etc., several characteristics of the deposition can be controlled.

It has been found that although sputtering can be employed to yield epitaxial silicon layers suitable for certain applications, certain characteristics of the deposited layers make them unsuitable for other applications. More particularly, silicon layers obtained as a result of sputtering usually exhibit poor longitudinal (i.e. parallel to the surface) conductivity but very good conductivity in a direction normal to the surface. Consequently, although sputtering has been used in order to fabricate diodes which do not require good longitudinal conductivity, sputtering has heretofore not been particularly useful for forming transistor bases for example, which require conductivity both normal to the surface and longitudinally.

In view of the foregoing, it is an object of the present invention to provide a method of forming silicon layers by sputtering, which layers exhibit good conductivity both normal to the surface and longitudinally.

Briefly, in accordance with a preferred method of practicing the invention, epitaxial silicon layers exhibiting

2

good conductivity both normal and parallel to their surfaces are achieved by heating the deposited silicon layer in an oxygen-free environment after deposition by sputtering.

The novel features that are considered characteristic of this invention are set forth with particularity in the appended claims. The invention will best be understood from the following description when read in connection with the accompanying drawings, in which:

FIGURE 1 is a sectional view illustrating a typical sputtering apparatus;

FIGURE 2 is an enlarged cross-sectional view illustrating two layers of silicon wherein the upper layer appears to be comprised of isolated crystallites; and

FIGURE 3 is a sectional view illustrating a substrate having silicon deposited thereon being heated in accordance with a preferred method of the present invention.

Attention is now called to FIGURE 1 which illustrates a sectional view of a sputtering apparatus 10 suitable for depositing semiconductor material such as silicon, on a substrate 12 supported (by means not shown) within the apparatus 10. Typically, the substrate 12 comprises an assembly of semiconductor devices and as an example, the top surface thereof can be formed of silicon. It should of course be appreciated however that the substrate could comprise other structures such as a slice of semiconductor material or a single crystal of sapphire, for example.

More particularly, the sputtering apparatus 10 is comprised of a cylindrical housing or chamber 14 formed of a conductive material, for example aluminum. An anode 16 is supported within and electrically connected to the housing by a conductive stem 17. A cathode 18 is also disposed in the housing spaced from and opposed to the anode 16. The cathode is formed of a material of the conductivity type and resistivity desired to be deposited on the substrate. A conductive stem 22 physically and electrically connected to the cathode 18, extends through an opening 24 in the end wall of the housing 14. The stem 22 is insulated from the housing 24 by a vacuum-tight insulating collar 26. A portion 28 of the housing projects inwardly around the cathode 18 to shield the cathode and stem 22.

In addition to the foregoing, the housing 14 is provided with an inlet aperture 30 and an exhaust aperture 32. The exhaust aperture 32 is used to evacuate the housing. The inlet aperture 30 is used to enable gas to be leaked into the housing.

As an example, consider that it is desired to deposit silicon of a particular conductivity type and resistivity onto the substrate 12. In order to do this, a cathode 18 having the desired conductivity type and resistivity is selected. A gas such as argon is permitted to enter the chamber through aperture 30 with the pressure within the chamber remaining substantially constant. An appropriate pressure can for example be approximately forty microns of mercury. A potential of 2000 volts or more is applied between the anode and cathode. This potential sets up a discharge between the anode and cathode which is due to a multiplication process in which collisions occur between positive ions and gas atoms which collisions produce more positive ions and electrons. The positive ions are drawn to the cathode and strike it with sufficient energy to eject therefrom atoms of the cathode material which collect on the substrate 12 forming a layer of the cathode material.

As a quantitative example, silicon can be sputtered from a .01 ohm centimeter N type silicon cathode onto a polished P type silicon wafer in an atmosphere of pure argon by utilizing a 5000 volt anode-cathode potential. In one hour, at a pressure of fifty microns, a silicon layer having a thickness of .8 micron can be deposited. Although such a layer will exhibit good conductivity normal to the sur-

face (i.e. from the top to the bottom surface of the layer), typically, layers deposited by sputtering as herein described, exhibit virtually no longitudinal conductivity (i.e. parallel to the layer surfaces). This fact can be confirmed by contacting the deposited layer with first and second probes spaced longitudinally from one another. A battery source and an ammeter can be connected in series between the probes. Usually, there will be no significant current flow between the probes demonstrating a very poor current conducting characteristic in the longitudinal direction. This characteristic is probably attributable to the fact that the deposited layer is formed of isolated crystallites.

More particularly, FIGURE 2 illustrates an enlarged view of a typical substrate 12 having a layer of silicon 34, deposited by sputtering, affixed thereon. It is believed that the deposited silicon layer 34 is comprised of oriented crystallites 36 which are separated by walls of silicon dioxide 38 which arise as a result of oxygen impurities.

In accordance with the present invention, the substrate 12 and deposited layer 34 of FIGURE 2 are heated in an oxygen-free environment in order to improve the longitudinal conductivity characteristic of the layer 34. For example, the substrate 12 can be supported on a graphite susceptor 40 supported within an induction furnace 42 heated by coil 44. Preferably, the furnace should be filled with hydrogen inasmuch as hydrogen will combine with any residual oxygen to assure an oxygen-free environment. The temperature of the deposited layer 34 should then be elevated to a level below the melting point of silicon and this temperature should be maintained for a duration dependent upon the temperature level. That is, the use of a higher temperature of a shorter interval will have substantially the same effect as the use of a lower temperature for a longer interval.

It has been found that after the deposited layer 34 has been heated to 1000° C., for example, for a period of about fifteen minutes, it demonstrates a markedly increased conductivity in the longitudinal direction. For example, a deposit which displayed no detectable conductivity prior to heating displayed a sheet resistance of only 2000 ohms per square after being heated. As a consequence, utilization of a sputtering deposition technique together with a subsequent heating step as demonstrated by FIGURE 3 enables transistor bases, for example, which require good longitudinal conductivity to be formed by sputtering. It is believed that the conductivity improves as a consequence of the elimination of the silicon dioxide walls 38 by a chemical reaction between the silicon dioxide and either excess silicon or hydrogen.

From the foregoing, it should be appreciated that a method has been disclosed herein for depositing epitaxial silicon layers by sputtering which layers exhibit good current conductivity characteristics in both longitudinal and transverse directions thus enabling them to be used to fabricate transistor bases, for example, where these characteristics are required.

What is claimed is:

1. A method of depositing a layer of silicon on a substrate, said method including the steps of:
 - sputtering atoms from a cathode formed of the silicon desired to be deposited by accelerating said atoms toward said substrate by an electric field;
 - collecting said sputtered atoms on said substrate to thus form a layer of said silicon thereon; and
 - heating said layer in an oxygen-free environment which is inert with respect to silicon at a temperature in the range of about 1000° C. to a temperature below the melting point of silicon but above 1000° C. for a time sufficient to reduce the resistivity to a fixed minimum value at the temperature within said range.
2. The method of claim 1 wherein said layer is heated to temperatures of approximately 1000° C. in a pure hydrogen environment.
3. The method of claim 1 including the additional step of supporting said cathode in an enclosed chamber and wherein said step of sputtering includes the step of establishing a discharge in said chamber.
4. A method of increasing the conductivity of a sputter deposited silicon layer in a direction parallel to the surfaces thereof including the steps of:
 - placing said layer in an oxygen-free environment which is inert with respect to silicon; and
 - heating said layer to temperatures of approximately 1000° C. for a time of approximately 15 minutes.
5. The method of claim 4 wherein said layer is heated in an environment of pure hydrogen.

References Cited

UNITED STATES PATENTS

3,021,271	2/1962	Wehner	204—192
3,323,954	6/1967	Goorissen	204—164
3,325,392	6/1967	Rummel	204—192

ROBERT K. MIHALEK, Primary Examiner

U.S. Cl. X.R.

29—576; 148—13; 264—345